An Optical Receiver and an Optical Communication System using the same

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an optical communication system and an optical receiver used in the optical communication system.

2. Related Prior Art

An optical communication system comprises an optical transmitter, an optical path and an optical receiver. The optical transmitter transmits signal light into the optical path, the optical path propagates the signal light and the optical receiver receives the propagated light. The optical communication system has an ability to send a huge amount of information with a high speed. To secure a quality of the propagated signal light, it is required to reduce an absolute dispersion accumulated from the transmitter to the receiver on the optical path.

On the other hand, typical optical fiber used in the optical communication system shows a zero-dispersion wavelength around 1.3 μm band, while a finite dispersion of +16ps/nm/km around 1.55 μm band where the optical communication system is performed. In the case that the optical path is constructed by such conventional optical fiber alone, the large dispersion will cause to deteriorate of the quality of the transmission signal.

To overcome the deterioration of the transmission quality due to large accumulated dispersion, a means for correcting the dispersion is placed on the optical path. The dispersion-correcting means has a negative dispersion to compensate the finite dispersion, which is a positive amount, of the optical path.

The dispersion correcting means is a dispersion-correcting fiber, for example. To adjust a ratio of a length of the single mode optical fiber, which is used in the optical path, to that of the dispersion-correcting fiber, the accumulated dispersion can be reduced, whereby enhancing the quality of the transmitted signal light.

However, the single mode fibers that are used in the optical path have various lengths and the dispersion attributed thereto show various values. Also, dispersion of the dispersion correcting-fibers has various values. Further, the optical transmitter and the optical receiver have respective tolerance for the dispersion. Therefore, the optical communication system should be designed by taking the above mentioned factors into account, which raises a designing cost and a management cost of the communication system.

Further, Since the dispersion-correcting fiber has a large transmission loss, several optical amplifiers to amplify the signal light must be installed on the optical path, which raises the cost for construction of the optical system. Moreover, because optical amplifiers accompany optical noises, the cost is required for reduce such optical noises to maintain the quality of the signal light. Also, distortion due to a non-linear effect in the optical fiber causes the deterioration of the transmitted signal light, because an output of the optical amplifier becomes so high that the non-linear effect of the optical fiber must be taken into account, which raises the cost of the communication system.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, an optical receiver comprises an optical-to-electrical converter, a current-to-voltage converter and a filter. The receiver receives a signal light transmitted through an optical fiber

and affected by an accumulated dispersion of the optical fiber. Therefore, the signal light received by the optical receiver has a frequency dependence due to the dispersion of the optical fiber. The optical-to-electrical converter converts the optical signal to an electrical current, and the current-to-voltage converter converts the electrical current to a voltage signal. The filter receives the voltage signal and outputs an electrical signal corresponding to the signal light received by the optical-to-electrical converter so that the filter compensates the frequency dependence of the signal light.

The filter may have a frequency response that the convex characteristic with a peak frequency from 2 GHz to 4 GHz. Since the frequency dependence of the signal light affected by the accumulated dispersion of the optical fiber shows an concave response at a frequency from 2 GHz to 4 GHz, the filter may compensates the convex dependence of the signal light.

The optical receiver according to the present invention may further have a control signal generator. The control signal generator includes a band-pass filter with a center frequency and a divider. The band-pass filter receives the voltage signal output from the current-to-voltage converter and outputs a filtered signal, the magnitude of which corresponds to that of the voltage signal at the center frequency. The divider receives the voltage signal from the current-to-voltage converter and the filtered signal from the band-pass filter, and output a control signal that is the ratio o the filtered signal to the voltage signal. The peak frequency of the filter may be changed by the control signal from the control signal generator.

The filter may include an inductor. The inductance of the inductor may be changed by the control signal from the control signal generator. Therefore, the frequency response of the filter may be varied dynamically.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows an optical communication system;

Figure 2 is a block diagram of an optical receiver according to the present invention;

Figure 3 shows a first embodiment of the filter circuit according to the present invention;

Figure 4 is a block diagram of the control signal generator;

Figures from 5A to 5B show frequency responses of the signal light transmitted through the optical fiber taking the effect of the laser chirping, which is calculated from the line width enhancement factor, into account;

Figure 6 shows a calculated frequency characteristic of the filter according to the first embodiment;

Figure 7 is a measured frequency characteristic of the filter;

Figure 8 is a monitored waveform of the optical signal;

Figure 9 is a monitored waveform of the output signal without the filter of the present invention;

Figure 10 is a monitored waveform of the output signal with the filter;

Figure 11 is a second embodiment of the filter circuit;

Figure 12 shows frequency responses of the filter of the second embodiment with the inductance as a parameter; and

Figure 13 is an embodiment to change the inductance dynamically.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will be described in detail as referring to drawings.

First, a configuration of an optical receiver according to the present invention will be described. Figure 1 is a block diagram showing the configuration of the optical communication system 1. The system 1 comprises an optical transmitter 10, an optical receiver 20, and an optical transmission path 30 made of an optical fiber. A signal light modulated by amplitude is transmitted from the optical transmitter 10, propagates in the optical path 30m and is received by the optical receiver 20.

First Embodiment

Figure 2 is a block diagram of the optical receiver 20. The optical receiver 20 comprises an optical-to-electrical converter 21, a current-to-voltage converter 22, a filter 23 and a controlling-signal generator 24. The optical-to-electrical converter 21 receives the signal light propagated in the optical path 30, and generates a signal current corresponding to a magnitude of the signal light. The optical-to-electrical converter 21 may be made of an Avalanche Photodiode. The current-to-voltage converter 22 has an input-terminal 22_1, an output-terminal 22_2, an amplifier A and a resistor R_0 connected to the amplifier in parallel and inserted between the input-terminal and the output terminal. The current-to-voltage converter 22 converts the current generated by the optical-to-electrical converter 21 and inputted to the input terminal 22_1 to a corresponding voltage signal V_1 and outputs to the output terminal 22_2.

The filter 23 has a peak characteristic at a frequency from 2 GHz to 4 GHz. The voltage signal V_1, which is output from the output terminal 22_2 of the current-to-voltage converter 22, is inputted at the input terminal 23_1 of the filter 23 and outputs a filtered signal V_2 from the output terminal 23_2. The frequency characteristic of the filter 23 may be variable.

The control signal generator 24 receives the voltage signal V_1 from the

current-to-voltage converter 22 at the input terminal 24_1, detects a magnitude of the V_1 at a frequency, and outputs a control signal S based on the magnitude of the V_1 from the output terminal 24_2. The control signal S controls the frequency characteristic of the filter 23. Thus, the frequency response of the filter 23 is adjusted by the control signal S.

Figure 3 shows an example of the filter 23. In Fig 3, the filter comprises resisters R_1 to R_3, inductors L_1 and L_2, and capacitors C_1 and C_2. From the input terminal 23_1 of the filter to the output terminal 23_2, a combination of R_1, L_1, L_2, and R_2 are connected in series. A node between L_1 and L_2 is connected to the ground through capacitor C_1 and also connected to the output terminal 23_2 of the filter 23 through capacitor C_2. The output terminal 23_2 is grounded through resistor R_3. By adjusting resistance of resistors from R_1 to R_3, inductance of inductors L_1 and L_2, and capacitance of capacitor C_1 and C_2, the frequency characteristic of the filter 23 that has convex with a peak at a desired frequency can be obtained.

Figure 4 shows a block diagram of the control signal generator 24. The control signal generator involves a band-pass filter 24_1 and a divider 24_2. The band-bass filter 24_1 filters a unique signal V_{f0} with the frequency component f_0 from the input signal to the input terminal 24_1. The divider 24_2 calculates a ratio of the filtered signal V_{f0} to the input signal V_1 and generates the control signal S based on this calculation. By selecting the filtering frequency f_0 of the band-pass filter, calculating the ratio V_{f0}/V_1 attributed to this filtering frequency, and generating the control signal S, the frequency response of the filter 23 can be adjusted by this control signal S.

An operation of the optical communication system 1 based on the present embodiment will be described. A signal light that is amplitude-

modulated and output from the optical transmitter 10 propagates in the optical path 30 and reaches the optical receiver 20. In the optical receiver, the optical-to-electrical converter detects the signal light and generates the corresponding photo-current. This photo-current is converted to a voltage form V_1 by the current-to-voltage converter 22. The filter 23 adjusts the frequency response of the signal V_1 and outputs the adjusted signal V_2. The control signal generator 24 detects the signal component, which has the center frequency f_0 and the quite narrow spectral width, and calculates the amount of the adjustment of the filter 23. The frequency characteristic of the filter 23 thus adjusted has a convex response with a peak frequencies from 2 GHz to 4 GHz.

On the other hand, the signal light reached the optical receiver has a concave characteristic at frequencies from 2 GHz to 4 GHz due to the accumulated dispersion of the optical path. Therefore, the frequency response of the signal light reached the optical receiver 20 and that of the filter 23 compensates with each other, and the voltage signal V_2 output from the filter has a waveform with a relatively reduced distortion.

Figures from Fig. 5A to 5D show results of the simulation that the signal light of 1.55 μm wavelength band with a frequency shift $\Delta\nu$, which is denoted by the equation

$$\Delta\nu = -\frac{\alpha}{4\pi}\frac{d}{dt}\ln(P(t))$$

where P(t) is the optical output power of the source and α is the line width enhancement factor, propagates in the single mode optical fiber with a length of 100km and accumulated dispersion of 1600 ps/nm, and finally reaches the optical receiver. The magnitude of α are -1, -2, -3, and -4 for Fig. 5A, Fig. 5B, Fig. 5C, and Fig. 5D, respectively. In a typical distributed feedback laser (DFB-

laser). is from -2 to -3.

As shown in figures, the frequency characteristic of the signal light at the input of the optical receiver has a bottom in the regions from 2 GHz to 4 GHz. On the other hand, the filter 23 of the present embodiment has a peak at the regions from 2 GHz to 4GHz. Moreover, the optical-to-electrical converter 21 and the curre-to-voltage converter 22 have a flat frequency response relatively to that of the filter. Therefore, the frequency response of the filter 23 compensates that of the signal light appeared in the input of the optical receiver whereby the signal V_2 output from the filter 23 can be reduced in the deformation of the waveform.

Figure 6 and figure 7 show the typical frequency response of the present embodiment. Figure 6 is a result of the circuit simulation, while figure 7 shows an experimental result. In both cases, the same circuit diagram is used. Practical values of circuit elements as follows: $R_1 = 40\Omega$, $R_2 = 50\Omega$, $R_3 = 50\Omega$, $L_1 = 3nH$, $L_2 = 1nH$, $C_1 = 1pF$, and $C_2 = 3pF$, respectively. For a comparison, the frequency response of the Bessel-Thomson filter is also shown in Fig. 6, which is typically used in a conventional optical receiver. From Fig. 6, the frequency response of the filter 23 has a peak at frequency around 2 GHz. The frequency response of the filter 23 can be adjusted by modifying resistance of resistors, capacitance of capacitors and/or inductance of inductors by the control signal S from the control-signal generator 24. For example, the peak frequency f_0 shifts to lower frequency by increasing the capacitance of C_1 and decreasing the capacitance C_2, while the peak frequency f_0 shifts to upper side by decreasing the resistance of R_1 and increasing the resistance R_3.

Figure 8 shows an eye-diagram of the signal light reached the optical receiver and Fig. 9 is the eye-diagram of the output of the Bessel-Thomson filter

when the signal light shown in Fig. 8 reaches the optical receiver with and passes the Bessel-Thomson filter. On the other hand, Fig. 10 shows the eye-diagram of the output from the filter 23 according to the present embodiment when the signal light shown in Fig. 8 is entered into the optical receiver 20. In the cases of Fig. 9 and Fig. 10, the optical fiber between the optical transmitter 10 and the optical receiver 20 is the single mode fiber, the length of which is 100km with the accumulated dispersion about 1600 ps/nm.

As shown in Fig. 8, the signal light propagated through the optical fiber of 100km length and reached the optical receiver 20 has a distorted waveform in the transition from a high-level to a low-level, namely the gradual slope from the high-level to the low-level, due to the accumulated dispersion of the optical path. Such distorted signal light is received by the optical receiver and the corresponding electrical signal output from the current-to-voltage converter 22 is inputted to the filter 23.

In the case that the filter is the conventional Bessel-Thomson filter that has no peak response to the frequency, the signal output from the filter reflects the gradual slope of the signal light as shown in Fig. 9. On the other hand in Fig. 10, the filter according to the present embodiment compensates the gradual slope of the signal light and the output thereof shows a steep transition.

<u>Second Embodiment</u>

Figure 11 shows another circuit for the filter 23. The circuit comprises three resistors R_{11}, R_{12} and R_{13}, three capacitors C_{11}, C_{12}, and C_{13}, and two inductors L_{11} and L_{12}. Tow combinations of R_{11}, L_{11} and C_{11}, and L_{12} and C_{12}, respectively, constitute low pass filters, while that of C_{13} and R_{13} constitutes a

high pass filter. Therefore, this circuit functions as a band pass filter. Figure 12 shows a frequency responses of the filter in Fig. 11. As shown in the figure, the peak frequencies change from 1.3 GHz to 3.5 GHz as inductance of the inductor L_{12} changes from 1 nH to 6 nH, while peak responses are constant.

One example for changing the inductance of the inductor L_{12} is shown in Fig. 13. In Fig. 13, plural inductors, each inductors are accompanied with a switch, are connected in series. Inductors whose accompanied switch is turned off contribute the filtering response. When the inductance of inductors $L_{12\text{-}1}$, $L_{12\text{-}1}$ and $L_{12\text{-}3}$ is 1 nH, 2 nH and 3 nH, respectively, and the SW_1 and SW_3 are turned off while the SW_2 is turned on, the total inductance will be 4 nH. By controlling the combination of turned-off switch by the control signal from the control signal generator, the frequency response of the filter 23 can be dynamically changed, whereby the depression of the frequency response appeared in the signal light due to the accumulated dispersion of the optical path can be effectively compensated.

Thus, by using the optical receiver 20 and the system 1 according to the present invention, the optical communication with a high quality may be realized, by which the distorted waveform of the signal light due to the accumulated dispersion of the optical path can be solved without installing any dispersion compensating fiber. Moreover, optical amplifiers to compensate the loss in the optical dispersion fiber may be cancelled, whereby reduction of the cost to design and to manage the optical communication system. Even in the case that the optical path is broken and is changed to the extra path using another optical fiber with dispersion different to the broken fiber, the present optical receiver may solve the problem of the distorted waveform due to the accumulated dispersion of the changed optical fiber.

From the invention thus described, it will be obvious that the invention and its application may be varied in many ways. For example, the configuration of the filter 23 may be other combinations of circuit elements and that of the control-signal generator 24 may be changed to other circuit. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended for inclusion within the scope of the following claims.